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Cross-Section-Area Method for Determining Density of Wool Fibers[1]

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INTRODUCTION

Rapid, accurate determinations of the density of the fleeces of individual sheep are necessary to the success of wool-improvement programs. Judgments depending on touch alone, though rapid, have not been sufficiently reliable. On the other hand the more exact laboratory methods, though reliable, have been too slow to be practical.

In recent years Burns and coworkers (*1*, *2*),[2] Hardy (*4*), Nordby (*12*), and Madsen and coworkers (*9*) in the United States, Wildman (*16*) in England, and Carter (*3*) in Australia have investigated methods for obtaining samples and determining wool density. Owing to their efforts, devices and methods have been developed for sampling a fleece for fiber density, this term signifying the number of fibers per unit area.

Time-consuming methods used in obtaining the number of fibers in a sample have restricted the study of density to small groups of sheep. Such methods usually have involved counting and weighing 100 or more fibers and relating the data obtained to the weight and number of fibers in the entire sample. In an effort to devise a reliable method that would be sufficiently rapid to permit the determination of the density of representative numbers of samples from large flocks of sheep an investigation was conducted at the United States Department of Agriculture, Beltsville Research Center, Beltsville, Md., during the year 1941. The method developed, described in this circular and hereafter referred to as the cross-section-area method, involves direct measurement of cross sections of wool-fiber bundles through the use of a modification of the compressometer (*14*).

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[1] Submitted for publication December 23, 1941.
[2] Numbers in parentheses refer to Literature Cited, p. 10.

The investigation at Beltsville was a direct outgrowth of earlier work of Hardy and Wolf (*7*), who found that the fineness of fibers in a given space could be determined when the size of area, closeness of packing, and number of fibers were known. Their results were in agreement with the theory that the size of a bundle depends on fineness, or mean diameter of the fibers; their number; and their closeness of packing. In the work described herein the last-mentioned factor is controlled, and when the fineness is known the number of fibers is determined from the size of the bundle.

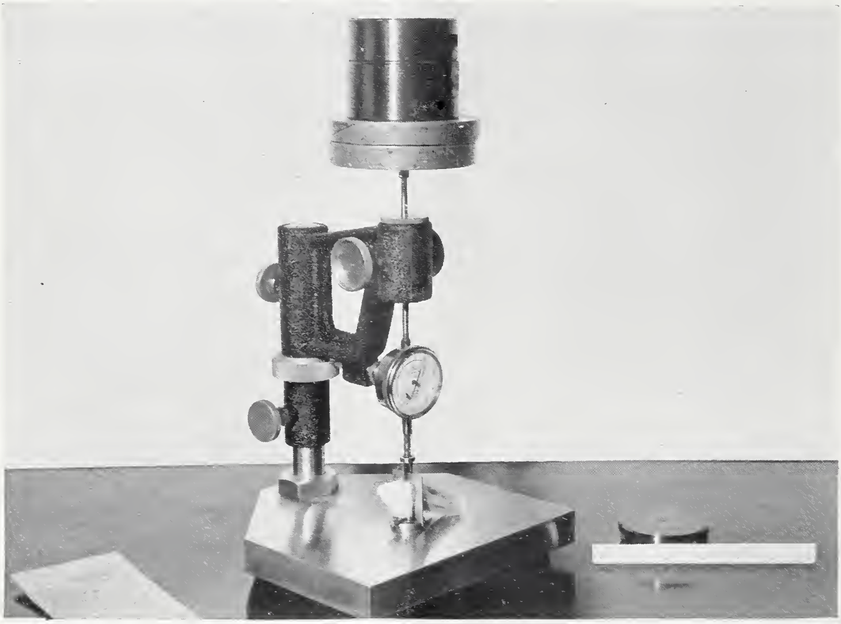

FIGURE 1.—Instrument for measuring the cross-section area of locks of wool, with bundle inserted for measuring.

APPARATUS AND TEST MATERIALS

Instruments have been designed by a number of investigators to measure the fineness of wool, the basis of measurement being the size of bundles of known numbers of fibers under constant pressure. One of the first instruments of this type was designed by Koehler, as reported by McMurtrie (*11*). Using the same principle, Küsebauch (*8*) included refinements in the construction of a similar apparatus. Mark (*10*) measured the thickness and resilience of elastic materials under various pressures, and Widney designed a "modulimeter" (*15*). More recently, Schiefer (*13, 14*) developed a compressometer for the same purpose.

In the investigation conducted at Beltsville the Schiefer instrument was modified to measure the sizes of bundles of wool fibers (fig. 1).

The top dial, which originally indicated pressures exerted on the thickness gage up to only 5 pounds (2.2 kg.), was replaced by an adapter to permit heavier dead-weight loads, which were required to obtain the necessary uniform pressure for the wool fibers. A holder for the fibers was designed with a slot 0.045 inch wide and 0.625 inch deep. A plunger was attached to the lower end of the shaft in place of the ball-and-socket joint. The dimensions of the plunger are such that it fits snugly into the slot of the fiber holder, thus permitting uniform compression of the bundle. The distance of the plunger end from the bottom of the slot is read directly in thousandths of an inch on the dial gage.

Wool-top samples of definite fineness and length, as shown in table 1, were used. The fineness and number of fibers were determined by making cross sections of the bundles of fibers by the methods reported by Hardy (*5*) and by Hardy and Wolf (*7*).

TABLE 1.—*Fineness and length of wool-top samples used in study*

Number of samples	United States numerical grade for fineness	Mean diameter	Mean length
		Microns	*Centimeters*
12	40s	37.9	5.8
10	56s	27.8	7.0
11	70s	19.9	4.8

The fiber ends of all bundles were kept in alignment. Wool-top bundles were tied in the middle with dental floss. All samples were cleaned in warm carbon tetrachloride, conditioned for 17 hours, and tested in a room with a constant temperature of 70° F., a relative humidity of 65 percent, and a dead-weight load of 5 kg.

FORMULAS FOR OBTAINING DENSITY OF FIBERS

As has been stated, the size of a bundle of fibers depends on three variables: Fineness, or mean diameter of the fibers; their number; and their closeness of packing.

The cross-section area of a bundle of fibers equals the width of the slot of the instrument multiplied by the lower dial reading. The dial reading, as indicated, is the distance of the plunger from the bottom of the slot. It is, therefore, possible to calculate the number of fibers in a bundle from the dial reading if the fibers are adjacently packed. The various types of packing, including the adjacent packing, are discussed by Hardy and Wolf (*7*). Formula 1 which follows has been used to calculate the number of fibers in a bundle:

$$N=\frac{R\times 45\times \overline{25.4}^2}{D^2}=29{,}032\ \frac{R}{D^2} \qquad (1)$$

in which N=number of fibers, R=dial reading in thousandths of an inch, 45=width of slot in thousandths of an inch, $\overline{25.4}^2$=factor for conversion of square thousandth inches to square microns, and D=average diameter of the fibers in microns.

Formula 1 may be simplified by substituting the factor F for the value $\frac{29{,}032}{D^2}$, as follows:

$$N = F \times R \qquad (2)$$

In table 2 various values of F are given for different values of the average diameter, D.

TABLE 2.—*Numbers of fibers in bundles of various mean fiber diameters*

Diameter of fibers in microns	Fibers per dial-reading unit	Diameter of fibers in microns	Fibers per dial-reading unit
10	290.3	23	54.9
12	201.6	25	46.5
15	129.0	27	39.8
16	113.4	28	37.0
17	100.5	30	32.3
18	89.6	35	23.7
19	80.4	40	18.1
20	72.6	45	14.3
21	65.8	50	11.6
22	60.0		

If the fleece area from which a sample has been taken is known, size of bundle alone offers a means of obtaining quickly a relative measure of fiber density of a fleece without reference to the number or fineness of the fibers. Formula 3 has been used to calculate the size of the bundle, D^2N:

$$D^2N = 29{,}032\ R \qquad (3)$$

In figure 2, D^2N is plotted against R, pressure being 5 kg., which resulted in adjacent packing of the fibers.

The use of formula 3 eliminates the necessity of using the value for mean diameter of the wool and thereby greatly expedites the measuring of fiber density.

SELECTION OF PROPER LOAD ON INSTRUMENT TO OBTAIN ADJACENT PACKING OF FIBERS

The selection of the proper load on the instrument to bring the wool fibers into adjacent packing is essential. Since the load on the instrument can be varied and the spacing or packing of the fibers depends on the load, a certain load may be selected to give adjacent packing to the fibers. When the adjacent packing is obtained, formula 3 gives the size of bundle and formulas 1 and 2 furnish the number of fibers.

To determine the proper load, bundles of wool prepared from wool tops of United States grades 40s, 56s, and 70s, and consisting of approximately 2,000 fibers each, were subjected to loads of 0 to 18 kg. The higher loads were obtained by placing the instrument on an ordinary platform scales and applying the load manually. Table 3 and figure 3 give the relative sizes of the bundles up to loads of about 7 kg. The difference in degrees of packing, as shown by the dial readings at lower loads for the 40s quality of wool, may be attributed to the smaller numbers of fibers for this grade and the freedom from crimp found in this coarser wool. Figure 4, *A–D*, shows the packing of the fibers up to 5-kg. loads. Theoretically, 18 kg. might be considered as

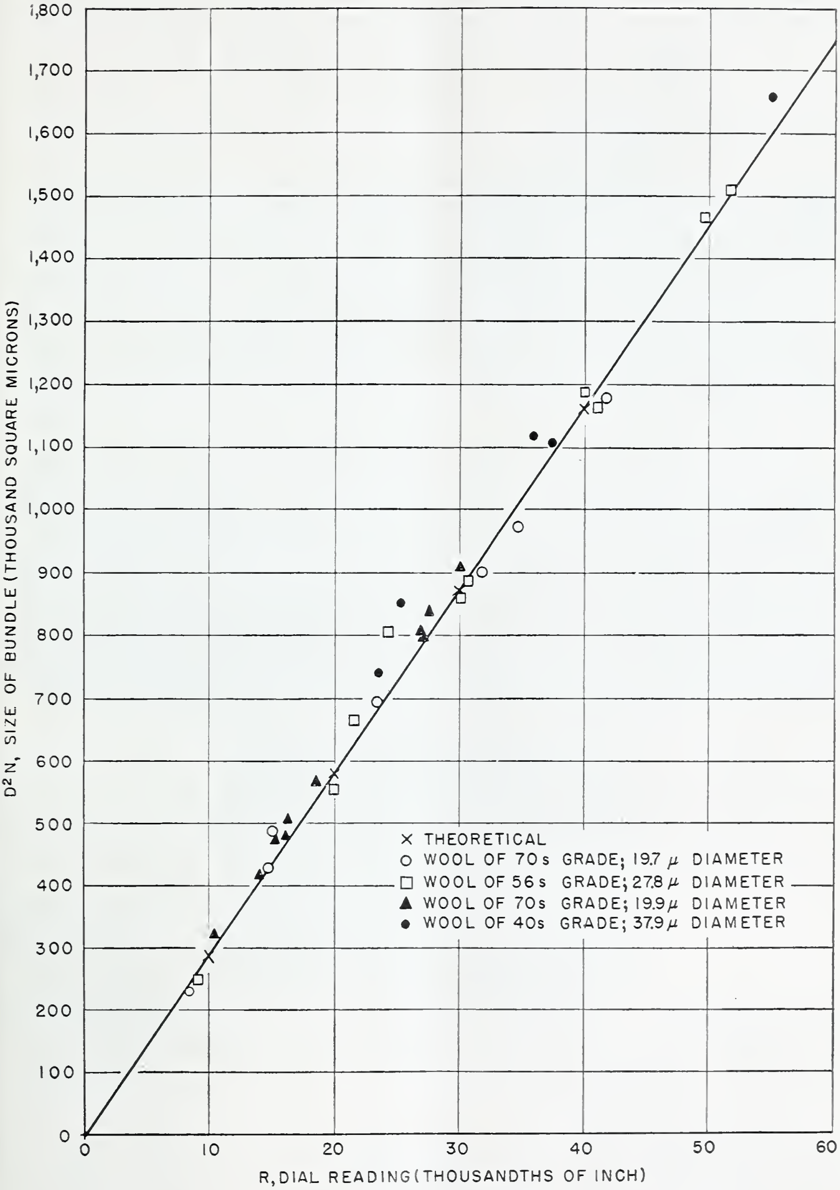

FIGURE 2.—Dial readings for wool bundles of various sizes.

a practical testing load. However, such high pressure offers a possibility of extreme distortion, as shown in figure 4, *E*, and in some cases might actually shear the fibers. The equipment therefore was constructed to operate up to about 7 kg., and for this reason table 3 and figure 3 do not include data for the higher pressures. Cross sections of the bundles were made while the fibers were maintained under pressure. The closer packing resulting from the increase in load helps to explain the shape of the curves in figure 3, which shows that the rate of change is rapid initially under small loads, when, as shown by figure 4, *A*, the fibers are loosely packed. At first the bundles are compressed easily until a load of 2 kg. is reached. From this point on the sizes of the bundles decrease at a slower rate, but adjacent packing is not obtained until about a 5-kg. load is applied. Further increases of the load make even smaller changes in the size of bundle, but the original contours of the fibers are gradually distorted. The contour is so altered with a load of 18 kg. that the slot may be considered solidly packed.

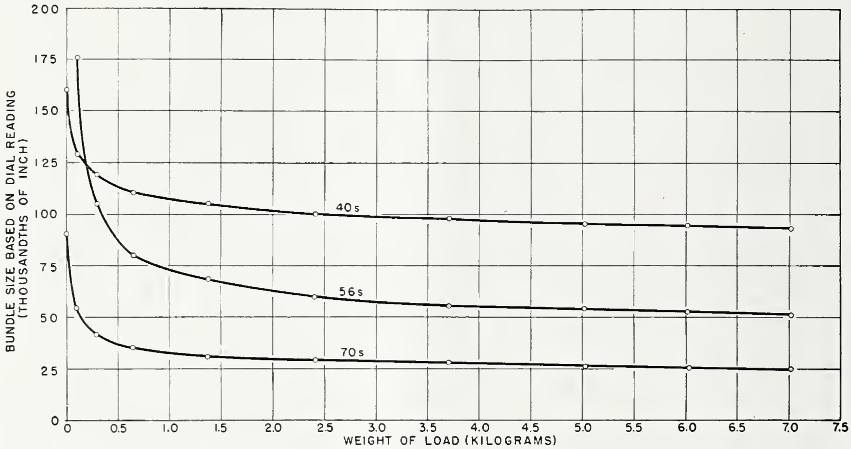

FIGURE 3.—Effect of various loads on the size of wool-fiber bundles.

TABLE 3.—*Relation between weight of load on bundle of wool fibers and the dial reading*

Load, in grams, on fiber bundle	Dial reading, in thousandths of an inch, for wool fibers of United States grade—			Load, in grams, on fiber bundle	Dial reading, in thousandths of an inch, for wool fibers of United States grade—		
	[1] 70s	[2] 56s	[3] 40s		[1] 70s	[2] 56s	[3] 40s
0	91. 5	213. 0	160. 0	645.0	37. 5	80. 5	112. 0
1.5	84. 7	206. 0	155. 5	1,375.0	32. 5	67. 5	106. 0
5.3	68. 0	205. 0	145. 5	2,420.0	29. 5	60. 5	101. 5
12.6	63. 2	200. 5	140. 5	3,720.0	28. 0	56. 5	98. 0
27.2	61. 5	190. 0	138. 0	5,040.0	26. 2	54. 0	95. 5
99.9	54. 5	177. 0	129. 5	6,040.0	25. 5	53. 0	94. 5
281.6	43. 0	105. 5	119. 0	7,040.0	24. 7	51. 5	93. 0

[1] 2,123 fibers per bundle.
[2] 2,246 fibers per bundle.
[3] 1,955 fibers per bundle.

After a study of the pressure curves and cross sections of the fibers, a 5-kg. load, which gives adjacent packing, was selected as a standard load for measuring the sizes of wool-fiber bundles.

COMPARISON OF CROSS-SECTION-AREA METHOD WITH SEVERAL OTHER METHODS

A comparison was made between this proposed method and three other methods, two of which involve the weighing of the fibers and the third the counting of every fiber in a cross section of a bundle. A statistical comparison is given in table 4. Results from the cross-section-area method were obtained by using a standard load of 5 kg., and the number of fibers was calculated by using formula 2. The results from gravimetric method A are based on the relationship between the weight of 100 representative fibers selected at random from

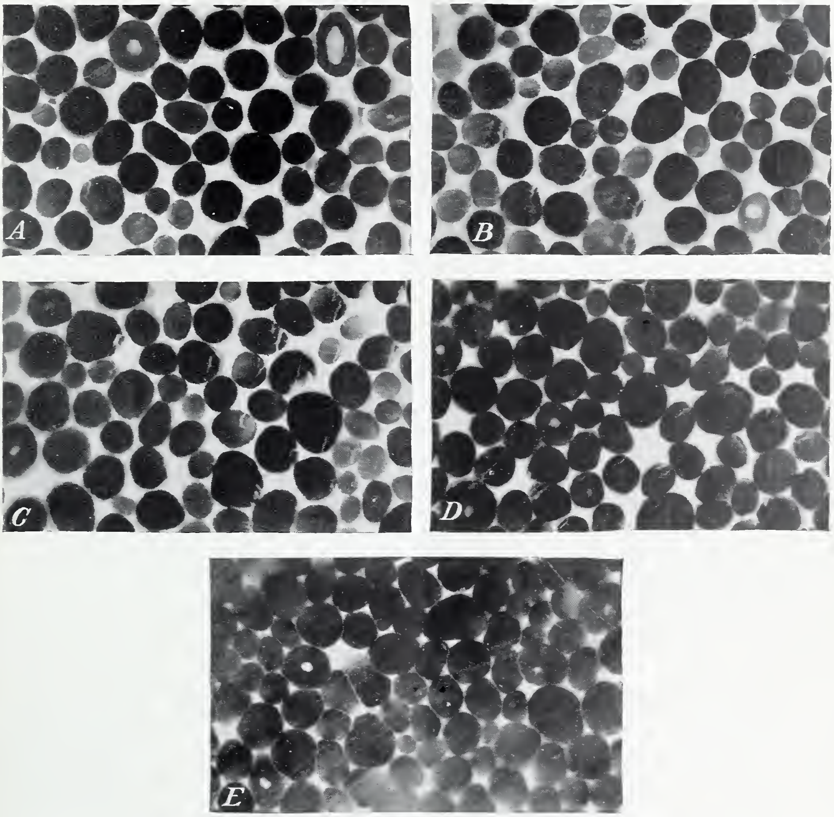

FIGURE 4.—Cross sections of fibers of United States grade 40s wool under various loads: *A*, Loosely packed fibers under 0.7 kg. load; *B*, loosely packed fibers under 1.3-kg. load; *C*, fibers under 2.6-kg. load (approaching adjacent packing); *D*, adjacently packed fibers under 5.0-kg. load; *E*, solidly packed fibers under 18-kg. load.

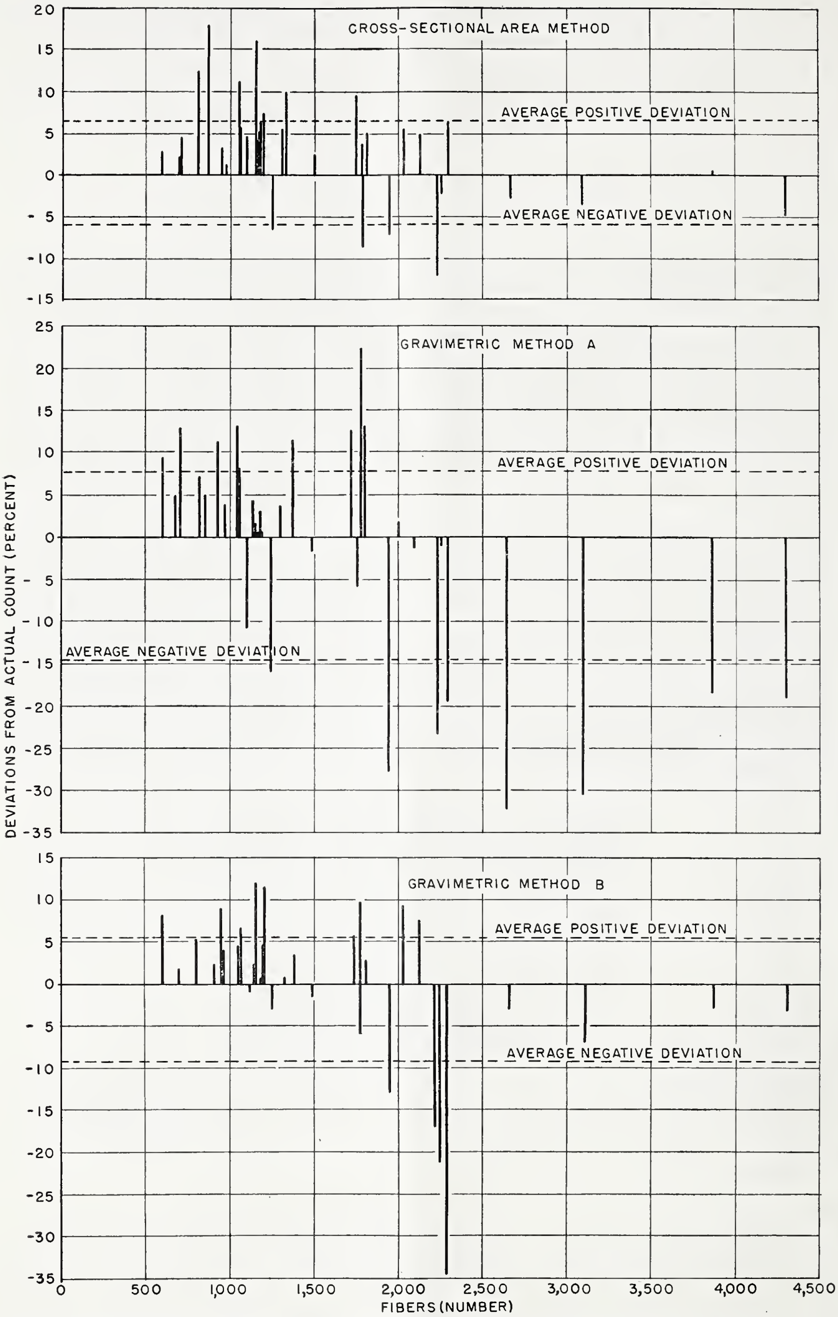

Figure 5.—Comparison of percentage of deviations, from the actual count, of the cross-section-area method and of gravimetric methods A and B.

the total bundle and the weight of the total bundle. The results from gravimetric method B were calculated by formula 4:

$$N=\frac{4W}{LD^2\pi S} \tag{4}$$

in which N=number of fibers, W=total weight of wool in clean conditioned bundle in milligrams, L=mean length in centimeters, D=diameter in microns, and S=specific gravity of wool.

In every case, highly significant correlations exist between the cross-section counts and the estimations.

Figure 5 compares graphically the percentage of deviations, from the actual count, of the cross-section-area method and of gravimetric methods A and B. The approximate average absolute deviation, from the actual count, for each of these three methods is as follows: Cross-section-area, 6.2 percent; gravimetric method A, 11.3 percent; gravimetric B, 7.5 percent. The proposed method, therefore, varies less from the actual count than either of the other two methods. Each method tends to overestimate the counted number of fibers in the case of the smaller numbers and underestimate the larger numbers. The cross-section-area method appears to be less affected by the number of fibers than the two gravimetric methods used.

TABLE 4.—*Comparison of cross-section-area method with other methods of measuring the size of bundles of fibers*

Method used	Mean	Correlation coefficient	Regression	Standard error	t[1]
	Number				
Cross-section area	1,610	[2]0.995	1.0636	0.04237	25.1
Actual count	1,636				
Gravimetric A[4]	1,771	[3].984	1.2952	.04153	31.2
Gravimetric B[4]	1,688	[3].981	1.078	.1194	9.03

[1] All highly significant; greatly exceed ±2.73 for 1-percent point, 31° of freedom.

[2] By the use of the Z transformation, the correlation does not deviate significantly from the expected value of unity.

[3] By the use of the Z transformation, the correlation deviates significantly from the expected value of unity.

[4] See text for description.

SUMMARY

The investigation reported was conducted at the United States Department of Agriculture, Beltsville Research Center, Beltsville, Md., during the year 1941. Its purpose was to devise an accurate, rapid method of determining the density of wool fibers.

The method developed consists in measuring the cross-section area of wool-fiber bundles under controlled conditions of temperature, humidity, and pressure. In the instrument designed for this purpose, the bundles of fibers are held in a slot 0.045 inch wide and 0.625 inch deep. The depth of the fibers in the slot is measured with a thickness gage in thousandths of an inch under a dead-weight load of 5 kg. The new method was compared with the three following methods and found to be rapid and reliable: One, known as gravimetric method A, consists in weighing 100 fibers and relating their weight to the weight of the entire bundle. Another, gravimetric method B, requires the calculation of the weight of 100 fibers from the diameter, specific gravity, and length of the fibers and relating this weight to the weight of the entire bundle. In the third method used for comparison, a bundle was cross-sectioned and each fiber was counted.

Reliability is indicated by the fact that the correlation and regression coefficients of this method on actual fiber counts approach unity. With the use of the cross-section-area method, about 50 samples can be measured in a working day of 8 hours, which greatly exceeds the number weighed and counted by methods previously used.

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